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1968-30

M. L. Burrows

Measurements of Electromagnetic Pulse Propagation in Various Soils

20 August 1968

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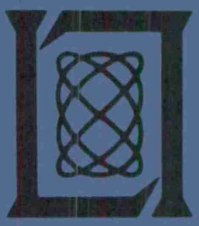

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

MEASUREMENTS OF ELECTROMAGNETIC PULSE PROPAGATION IN VARIOUS SOILS

M. L. BURROWS

Group 66

TECHNICAL NOTE 1968-30

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LEXINGTON MASSACHUSETTS

ABSTRACT

Measurements of the propagation velocity and attenuation of 2.5, 5, and 10 nS pulses in various soils with varying water contents have been made by packing the soils into a specially built coaxial line. From the table of results it is also possible to infer qualitatively the amount of pulse disperison.

The soils tested range from pure sand, which is essentially non-dispersive and has low attenuation, through various loams of moderate dispersion and attenuation to the highly-dispersive, highly-attenuating pure clays.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

MEASUREMENTS OF ELECTROMAGNETIC PULSE PROPAGATION IN VARIOUS SOILS

An experimental program of pulse propagation measurements in a variety of different soils has been carried out. Interest has centered on pulse lengths of the order of 5 to 10 nS, which implies a frequency spectrum extending from 0 to about 300 MHz. The measurements were made by packing the soil under test into a coaxial line, applying an input pulse at one end and observing the transmitted pulse at various positions along the line by means of a voltage probe and a sampling oscilloscope.

The line consisted of an 8-foot long brass channel, 2-inches wide and 1-inch deep, a brass-strip center conductor, 1 inch by 1/8 inch, which was connected to the coaxial connectors in the end plates of the channel, and a slotted lid. The empty channel was first packed with soil to a depth of slightly less than half the full channel depth, then the center conductor was laid on top of the packed soil and soldered to the coaxial connectors, then the remaining interior space was packed with the soil and the lid placed in position.

The transverse dimensions of the line were chosen to be small compared with the smallest wavelength likely to be encountered in the soils to be tested and yet large enough to allow granular material to be packed in it without difficulty. The first requirement ensured that only the TEM mode would propagate in the line, thereby simulating plane wave propagation in an infinite medium.

During the tests, the coaxial connector at the far end of the line was left open circuited, so that perfect reflection of the propagating pulse

would take place. Thus a measurement made with the voltage probe at the midpoint of the line would show first the pulse shape 4 feet deep into the medium and then, later, the pulse reflected back from the far end having propagated a total distance of 12 feet. Multiple reflections back and forth between the open circuit at the end of the line and the mismatch at the input to the line were occasionally observed, but usually the attenuation through the soil was so large that the pulse was undetectable even at the 12-foot effective range.

In Figures 1 and 2 some examples of the oscilloscope display are reproduced for a particular soil sample. Three different probe positions, namely 0, 2, and 4 feet from the input end, were used for each of two pulse lengths, 5 and 10 nS. Thus the curves actually show effective ranges of 0, 2, 4, 12, 14, and 16 feet, although the pulse height observed at the 16-foot range is actually the sum of the pulse incident upon the mismatch at the line input together with its reflection at that mismatch.

The curves in the figures show clearly the attenuation, distortion, and spreading experienced by the pulse as it propagates through the medium. In addition, the effective speed of propagation is indicated by the time displacement of the various down-range pulses from the leading edge of the input pulse.

A summary of the test results obtained on nine different soils is presented in Table I. Wherever a dash occurs in place of an entry, no measurement was made. A question mark indicates that although the indicated measurement was made, the pulse was too small to be identified on the oscilloscope display.

The "water content" entries are the weight of water in the soil sample expressed as a percentage of the weight of the dry soil. The "liquid limit" entries give the maximum water content at which the soil in question has mechanical stability. The speed of propagation is recorded in the table as a slowness number, which is equal to the speed of light in free space divided

TABLE I

SUMMARY OF RESULTS

Soil	Liquid Limit %	Water Content %	Slow-ness	Height Ratio								
				10 nS pulse			5 nS pulse			2.5 nS pulse		
				2 ft	4 ft	12 ft	2 ft	4 ft	12 ft	2 ft	4 ft	12 ft
South Carolina Clay Loam	42.0	8	2.2	--	1.25	2.25	--	1.5	3.9	--	2.2	7.5
		17	3.0	--	1.55	4.3		1.9	9.5	--	3.5	20.0
		20	3.8	--	2.6	10.0	--	3.1	17.0	--	5.7	?
		26	4.6	--	1.8	10.4	--	2.8	19.4	--	4.8	?
Ottawa Sand	--	0	1.6	--	1	1	--	1	1	--	1	1
		wet	4.8	--	1.4	2.8	--	1.4	2.8	--	1.4	2.8
New England Peat Loam	38.0	15	2.3	--	1.2	1.7	--	1.3	2.0	--	1.4	2.8
		23	2.9	--	1.4	2.7	--	1.5	3.6	--	1.6	4.7
		34	4.6	--	1.9	7.0	--	2.4	13.0	--	2.8	18.4
New England Clay Loam	34.1	14	2.3	--	1.2	1.8	--	1.3	2.2	--	1.35	2.9
		18	2.6	--	1.2	1.6	--	1.3	2.0	--	1.5	2.8
		23	3.3	--	1.3	2.6	--	1.3	3.6	--	1.6	4.8
Bentonite	710	39	2.5	1.2	1.4	3.3	1.2	1.6	5.5	--	--	--
		68	3.2	1.8	4.2	?	2.3	8.0	?	--	--	--
		80	4.0	2.7	15.0	?	5.0	28.0	?	--	--	--
		102	5.0	6.5	?	?	--	--	--	--	--	--
		108	5.2	6.5	?	?	--	--	--	--	--	--
		116	6.0	7.0	?	?	16.0	?	?	22	?	?
Illite	120	5	2.0	1.4	1.6	3.8	1.5	2.2	8.5	--	--	--
		13	2.5	1.8	2.7	?	2.1	4.8	?	--	--	--
		19	3.0	2.5	6.3	?	--	6.6	?	--	--	--
		28	3.8	4.5	?	?	--	--	--	--	--	--
		31	4.0	5.6	?	?	--	--	--	--	--	--
		34	4.0	7.0	?	?	11.0	?	?	18	?	?

TABLE I (Continued)

Kaolinite	53	3 20 31 44 49 54	1.8 2.8 3.4 4.0 4.2 4.6	1.4 1.6 -- -- -- --	2.0 2.3 3.4 3.5 3.7 3.6	7.0 8.7 ? ? ? ?	1.6 1.8 -- -- -- --	2.7 3.4 5.4 -- -- 5.5	16 19 ? -- -- ?	-- -- -- -- -- --	-- -- -- -- -- 10	-- -- -- -- -- ?
Millstone [1]	--	12	3.1	--	1.4	3.2	--	1.5	4.6	--	2.0	9.0
Ft. Belvoir [2]	--	--	2.1	--	1.3	2.2	--	1.6	3.6	--	2.2	8.0

[1] New England Sandy Clay

[2] Virginia Sand

by the speed of pulse propagation. The speed of propagation was calculated by dividing the range by the time displacement between the leading edges of the input pulse and the down-range pulse.

Since it is not possible to define a single number giving the attenuation per meter for pulse propagation in a dispersive medium, it was decided that a direct comparison of the height of the down-range pulse to the height of the input pulse would be the best method of defining the attenuation. Accordingly, a ratio of these quantities is entered in the table for each soil specimen, each input pulse length, and each range.

No separate measure of the pulse distortion was made, but the severity of the distortion can be inferred by comparing the height ratios obtained for two different pulse lengths at the same range. Where these numbers are close, the distortion is small for pulses of the widths chosen. Another comparison is between two different ranges at the same input pulse length. If the distortion is small, the height ratio at 12 feet, for example, should be equal to the height ratio at 4 feet raised to the third power.

It is difficult to make any comprehensive conclusions about the results, except that dry sand is essentially a perfect dielectric while wet pure clay (e.g., Bentonine) is both very attenuating and very dispersive. Commonly occurring soil mixtures appear to be sufficiently low in attenuation for pulse propagation over ranges of up to perhaps 20 feet to be feasible.

Since wet sand is essentially non-dispersive for the pulse lengths used in these experiments, one concludes that the dispersion observed in the various other soils tested is due to the low-energy ion-exchange bonds known to be present in water-clay mixtures. The characteristic frequencies of these bonds, since the bonds are of low energy, must be much lower than the characteristic frequency of the higher-energy water molecule bond and therefore lie closer to the spectrum of the pulses used in the soil tests. Thus it appears that the more clay and the more water in a soil, the more attenuating and dispersive it will be.

One other factor to be considered is the possibility that the water contained in the soil possesses an appreciable conductivity itself due to the presence of dissolved salts. It is known, for example, that ocean water has an attenuation per meter measured in tens of dB in the VHF frequency band. Thus it is likely that where the salt content of the ground water is high and where, in addition, the water content of the soil is high, the effect of the dissolved salts on pulse propagation will be marked. No measurements have been made to investigate this effect however.

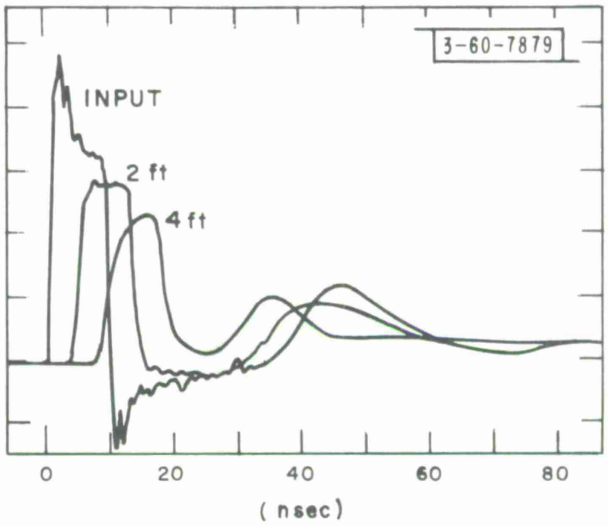

Fig. 1. Oscilloscope displays obtained with a 10-nsec pulse propagating through illite of 5% water content.

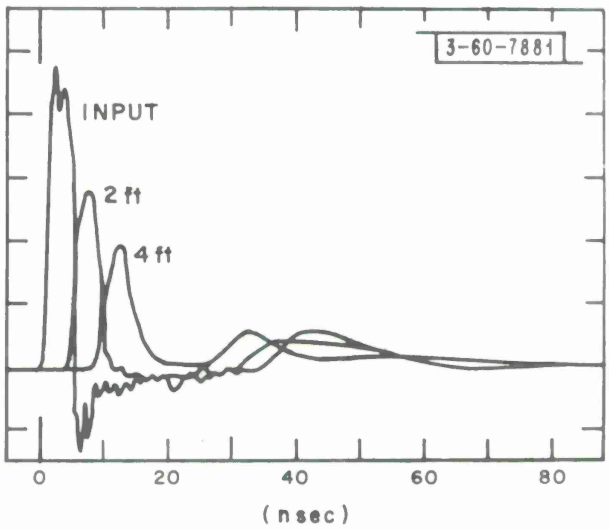

Fig. 2. Oscilloscope displays obtained with a 5-nsec pulse propagating through illite of 5% water content.

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The soils tested range from pure sand, which is essentially non-dispersive and has low attenuation, through various loams of moderate dispersion and attenuation to the highly-dispersive, highly-attenuating pure clays.

14. KEY WORDS

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